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W^+Z and $W^+\gamma^*$ Backgrounds to Strong W^+W^+ Scattering at the LHC[1]

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Abstract

Because of inevitable blind spots at high rapidity and low transverse momentum, the process $\overline{q}q \to l^+l^-\, l^+\nu$ provides a surprisingly large background to the $W^+W^+ \to l^+\nu\, l^+\nu$ signal associated with strong WW scattering. Previous calculations of the total background are approximately doubled, and the estimate of the "no-lose" luminosity at the LHC to observe manifestations of the electroweak symmetry breaking mechanism is increased to between ~ 100 and ~ 140 fb^{-1}.

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Introduction

In the search for the mechanism of electroweak symmetry breaking, strong WW scattering above 1 TeV in the WW center of mass energy is the signal of "last resort" since it occurs if other, typically larger signals below 1 TeV, such as Higgs bosons, do not.[1] A collider with enough energy and luminosity to observe strong WW scattering can provide evidence of the symmetry breaking mechanism whatever form it may take. Using a QCD-like chiral Lagrangian with a dominant "ρ" meson to study strong scattering in the WZ and W^+W^+ channels, we found a complementary relationship between the resonant "ρ" signal, best observed in the WZ channel, and nonresonant scattering in the W^+W^+ channel.[2] In that model we found that the worst case is for $m_\rho \simeq 2.5$ TeV, corresponding to minimal one-doublet technicolor with $N_{TC} = 2$, for which the "ρ" is too heavy to observe directly at the LHC as a WZ resonance but is still light enough for chiral dynamics associated with t and u-channel "ρ" exchange to suppress nonresonant W^+W^+ scattering. For experimental cuts that optimize the signal relative to the "irreducible" backgrounds, we used this worst case to estimate a "no-lose" luminosity $\simeq 60$ fb^{-1} for the LHC operating at 14 TeV. Similar results[2] have been reported by Bagger et al.[3]

The irreducible backgrounds are those with the same final state as the signal. For strong W^+W^+ scattering the leading irreducible backgrounds are the order α_W^2 and $\alpha_W\alpha_S$ amplitudes for $qq \to qqW^+W^+$ with the former computed in the standard model with a light Higgs boson, $m_H \leq 100$ GeV. We consider leptonic decays, $W^+W^+ \to l^+\nu l^+\nu$ where $l = e$ or μ. In our previous study we used cuts on the e^+ and μ^+ leptons and a veto of events with high p_T jets in the central region, to enhance the longitudinally polarized W^+W^+ pairs of the signal over the transverse-transverse and transverse-longitudinal pairs of the background.

In the W^+W^+ channel both we and the authors of reference [3] did not use a tag on forward jets, seeking instead to isolate a clean signal by means of harder cuts on the lepton variables. A jet tag may be necessary if we hope to detect gauge boson pairs in "mixed decays", where one boson decays to

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[2]One important difference is that we "customize" the experimental cuts to obtain the optimal significance for each model while Bagger et al. use a single set of cuts, optimized for the standard model with $m_H = 1$ TeV, for all models.

hadrons and the other to leptons, but it may not be needed if both bosons decay to leptons, as is essential for the like-sign WW signal. The use of hard leptonic cuts for purely leptonic decays is especially effective for strong scattering models since they are characterized by the hardest diboson energy distributions consistent with unitarity. If this strategy suffices it has the advantage of being cleaner theoretically and experimentally. Estimates of jet tagging efficiency are uncertain because the transverse momentum and rapidity distributions of the forward jets are probably sensitive to QCD corrections and because the jet detection efficiency in the forward region is sensitive both to details of the detector and to how the jets hadronize. If both strategies can be made to work they will complement one another.

Other backgrounds (not irreducible) that can fake the l^+l^+ signal, from $\bar{t}t$[4] and $\bar{t}tW^+$[5], can be suppressed. We have independently confirmed the conclusions of [4] for the $\bar{t}t$ background. After cuts the t quark backgrounds are much smaller than the irreducible background from $qq \rightarrow qqW^+W^+$.

In a different approach to the $qq \rightarrow qqW^+W^+$ signal Azuelos, Leroy, and Tafirout considered tagging the two forward quark jets.[6] Their study includes a simplified simulation of the proposed ATLAS detector. In addition to the irreducible backgrounds and the $W\bar{t}t$ background, they also considered $\bar{q}q \rightarrow W^+Z \rightarrow l^+\nu l^+l^-$ where the l^- escapes detection. The $\bar{q}q$ annihilation amplitude is computed with PYTHIA, which includes gluon radiation. To satisfy the jet tag two gluons must accompany the WZ bosons, so that the contribution of these WZ events to the background is well below that of the order $\alpha_W^2 \, qq \rightarrow qqW^+W^+$ amplitude, which is also the dominant background in their analysis. It remains to evaluate the order α_W^2 amplitude background from $qq \rightarrow qqWZ$, which after the jet tags and central jet veto is probably larger than $\bar{q}q \rightarrow WZ$.

We are motivated by the study of Azuelos et al. to consider the effect of the WZ background in our approach. We have gone beyond the WZ background to include the full set of 10 tree level Feynman diagrams[3] for the process $\bar{q}q \rightarrow l'^+\nu' l^+l^-$ where l and l' are electrons or muons.[4] Three diagrams correspond to WZ production and three to $W\gamma^*$. We find after cuts that the contributions

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[3]The amplitudes are evaluated using HELAS[7] as implemented in MADGRAPH[8].

[4]We neglect the small interference between the like-sign leptons when $l = l'$.

not attributable to $\overline{q}q \to WZ$ constitute nearly half of the total $\overline{q}q \to l'^+\nu'l^+l^-$ background.

After reviewing the model and the irreducible backgrounds we describe the $\overline{q}q \to \overline{l}\nu\overline{l}l$ background and evaluate its effect on the observability of the $W^+W^+ + W^-W^-$ signal. We then briefly discuss the sensitivity of the results to collider energy and detector coverage and the background from $qq \to qqWZ$. We conclude with a few remarks, including the observation that *strong scattering* in $qq \to qqWZ$ provides a useful "pseudo-amplification" of the strong W^+W^+ scattering signal.

Signal and Irreducible Background

The computation of the signal and irreducible background is as in reference [2], which the reader can consult for additional details and references. Here we only sketch the essential points.

In [2] we considered the strong scattering of longitudinally polarized gauge bosons in the channels $qq \to qqW^\pm Z$ and $qq \to qqW^+W^+/W^-W^-$. If the electroweak $SU(2)_L \times U(1)_Y$ is broken by a strong force, the scattering of longitudinally polarized gauge bosons of energy $E \gg M_W$ is approximately equal to that of the corresponding unphysical Goldstone bosons. At low energies compared to the mass scale of the new strong force the Goldstone boson interactions can be described by an effective Lagrangian like the chiral Lagrangian that describes QCD. To explore the relationship between resonant WZ and nonresonant W^+W^+ strong scattering signals we assumed QCD-like dynamics, with an effective Lagrangian incorporating a dominant "ρ" meson[9] and with K-matrix unitarization. Applied to QCD the model provides a good description of both $\pi^+\pi^0$ and $\pi^+\pi^+$ scattering data to unexpectedly high energy $\simeq 1.2$ GeV.

Applied to electroweak symmetry breaking the model exhibits a complementary relationship between the resonant WZ channel and the nonresonant W^+W^+ channel. For smaller m_ρ the resonant $\rho \to WZ$ signal is large while the nonresonant W^+W^+ signal is suppressed. For very large m_ρ the resonant WZ signal is unobservable but nonresonant W^+W^+ scattering is large, approaching the K-matrix unitarization of the low energy theorem as $m_\rho \to \infty$.

In [2] we considered only irreducible backgrounds to the W^+W^+ signal. We used cuts on the l^+l^+ decay products (rapidity, $\eta(l^+)$, transverse momentum,

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$p_T(l^+)$, and the azimuthal angle between the two leptons, $\phi(l^+l^+)$) that exploit the differing energy dependence and polarization of signal and background. We also imposed a veto on events with a central, high p_T jet, that also exploits the boson polarizations. We optimized the cuts in $p_T(l^+)$ and $\phi(l^+l^+)$ for each model to establish the minimum luminosity for a significant signal.

The observability criterion in [2] and in this paper is

$$\sigma^\uparrow = S/\sqrt{B} \geq 5 \tag{1}$$

$$\sigma^\downarrow = S/\sqrt{S+B} \geq 3 \tag{2}$$

$$S \geq B, \tag{3}$$

where S and B are the number of signal and background events, and $\sigma^\uparrow$ and $\sigma^\downarrow$ are respectively the number of standard deviations for the background to fluctuate up to give a false signal or for the signal plus background to fluctuate down to the level of the background alone. In addition we require $S \geq B$ so that the signal is unambiguous despite the systematic uncertainty in the size of the backgrounds, expected to be known to within $\leq \pm 30\%$ after "calibration" studies at the LHC.

The statistical criterion, equations (1) and (2), apply to the detected events, i.e., *after* efficiency corrections are applied. Assuming 85% detection efficiency for a single isolated lepton,[10] our criterion for the W^+W^+ signal applied to the uncorrected yields is $\sigma^\uparrow > 6$ and $\sigma^\downarrow > 3.5$.

The worst case is at an intermediate value of m_ρ for which neither the WZ nor the W^+W^+ signal is large. In [2] and in this study we find it is at $m_\rho \simeq 2.5$ TeV, corresponding to minimal technicolor with $N_{TC} = 2$. The best signal for that case is in $W^+W^+ + W^-W^-$ scattering. We found in [2] that it could be observed with 63 fb^{-1}, which was the basis for our estimate of the "no-lose" luminosity.

The $\bar{q}q \to l\nu\bar{l}l$ Background

We now consider the background to the W^+W^+ signals from $\bar{q}q \to l^+\nu l^+l^-$ where the l^- escapes detection. Any detector will have unavoidable blind spots at low transverse momentum and at high rapidity. At very low p_T muons will not penetrate the muon detector, electrons or muons may be lost in minimum bias pile-up, and for low enough p_T in a solenoidal detector they will curl up

unobservably within the beam pipe. Muon and electron coverage is also not likely to extend to the extreme forward, high rapidity region.

We have tried to make reasonable though aggressive assumptions about the observability of the extra electron or muon.[5] We assume rapidity coverage for electrons and muons of $\eta(l) < 3$, roughly as expected for the ATLAS detector. Within this rapidity range we assume that isolated e^- and μ^- leptons with $p_T(l) > 5$ GeV can be identified in events containing two isolated, central, high p_T e^+'s and/or μ^+'s. We assume that electrons (but not muons) with $1 < p_T(l) < 5$ GeV can be identified if they are sufficiently collinear ($m(e^+e^-) < 1$ GeV) with a hard positron in the central region. For $p_T(e^-) < 1$ GeV we consider electrons to be unobservable.

It is instructive to examine the $\eta(e^-)$ and $p_T(e^-)$ distributions for electrons that survive this set of cuts. They are shown in figure 1 for $\overline{q}q \to e^+e^-\, l^+\nu$ events where $l = e$ or μ. The two positive leptons are required to satisfy $|\eta(l^+)| < 2.0$, $p_T(l^+) > 60$ GeV, and $\cos\phi(l^+l^+) < -0.6$. The solid lines are based on the full set of 10 Feynman diagrams while the dashed lines are for the W^+Z contribution only, defined as events for which the $l^+\nu_l$ and e^+e^- masses lie within ± 10 GeV of M_W and M_Z respectively. The WZ contribution dominates for $\eta(e^-) > 3$ and $p_T(e^-) > 5$ GeV, while the other components dominate for $\eta(e^-) < 2$ and $p_T(e^-) < 5$ GeV. The total number of events contributing to figure 1 is 27, of which just half, 13.7, are from WZ production.

Another noteworthy feature of the $l^+l^-l^+\nu$ background is the pronounced peaking of the l^+ rapidity distribution toward large $\eta(l^+)$. While the irreducible backgrounds are also more sharply forward peaked than the relatively isotropic signal, the $\eta(l^+)$ distribution from $l^+l^-l^+\nu$ is even more strongly peaked. In [2] we found no advantage from tightening the rapidity cut below $\eta(l^+)^{MAX} = 2$, but we now find that smaller $\eta(l^+)^{MAX}$ increases the significance of the signal for some models.

A crucial issue beyond the scope of this work is the efficiency with which the extra lepton can be rejected when it falls within the specified acceptance region. Following the slogan "when in doubt, throw it out", background veto efficiencies

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[5] We thank K. Einsweiler and M. Gilchriese for several very useful discussions of the possible capabilities of the ATLAS detector.

much higher than signal detection efficiencies should be possible. The effect of an aggressive veto on the signal efficiency must be considered, but we suspect it is not great. We have studied all four models assuming 100% veto efficiency and have also studied the effect in the worst-case model of 98, 95 and 90% veto efficiencies.

Results

As in [2] we veto events with central, high transverse momentum jets ($\eta_J < 2.5$ and $p_{TJ} > 60$ GeV). Together with the leptonic cuts this virtually eliminates the irreducible $O(\alpha_W \alpha_S)$ gluon exchange background and is also quite effective against the $O(\alpha_W^2)$ background amplitude.[5] We scan the three dimensional parameter space of cuts on the like-sign leptons, consisting of the single lepton rapidity $\eta^{MAX}(l)$, the single lepton transverse momentum $p_T^{MIN}(l)$, and the azimuthal angle between the like-sign leptons, $[\cos\phi(ll)]^{MAX}$.

The signal amplitude is determined by the mass and width of the ρ meson. We consider minimal one-doublet technicolor with $N_{TC} = 2, 3, 4$ which by large N_{TC} scaling from QCD implies $m_\rho \simeq 2.52, 2.06, 1.78$ TeV respectively. To illustrate the possibility that the mass scale of the new quanta could be even heavier, we consider a fourth model with m_ρ set to an arbitrarily large value, 4 TeV, and the width Γ_ρ fixed by scaling from QCD.

Figure 2 shows the integrated, single lepton transverse momentum distribution for $l^+l^+ + l^-l^-$ leptons, i.e., the number of events per 100 fb^{-1} with like-sign lepton $p_T(l) > p_T^{MIN}(l)$ as a function of $p_T^{MIN}(l)$. The signal is for $m_\rho = 2.52$ TeV, and $\eta^{MAX}(l)$ and $[\cos\phi(ll)]^{MAX}$ are set to their optimum values (see table 1). At the optimum, $p_T^{MIN}(l) = 130$ GeV, the signal is ~ 2.5 times bigger than the background, with equal contributions from $\overline{q}q \to l^\pm \nu_l l^+ l^-$ and the irreducible background.

For each model and for every point in the three dimensional parameter space ($\eta^{MAX}(l)$, $p_T^{MIN}(l)$, $[\cos\phi(ll)]^{MAX}$) we computed the integrated luminosity needed to satisfy the acceptance corrected observability criterion. The smallest is then the minimum luminosity for that model, $\mathcal{L}_{MIN}$, and the corresponding point in the ($\eta^{MAX}(l)$, $p_T^{MIN}(l)$, $[\cos\phi(ll)]^{MAX}$) parameter space is the optimal cut. Table 1 reports the minimum luminosity for each of the four values of m_ρ for both the resonant WZ and nonresonant like-sign WW signals. In each case both

charge channels are included, that is, $W^+Z + W^-Z$ and $W^+W^+ + W^-W^-$.

For the resonant WZ channel table 1 records only $\mathcal{L}_{MIN}(WZ)$ — details can be found in [2]. For the like-sign WW signals the table includes the minimum luminosity, the optimized cuts on the like-sign leptons, the resulting number of signal and background events per 100 fb^{-1}, and the relative contributions of the three background components.

Complementarity of the resonant and nonresonant channels is evident in the inverse relationship between $\mathcal{L}_{MIN}(WZ)$ and $\mathcal{L}_{MIN}(WW)$ in the table. For the like-sign WW channel the biggest signal occurs for the heaviest ρ meson, $m_\rho = 4$ TeV, with a signal meeting the significance criterion for 77 fb^{-1}. The WZ signal is smallest for that case, and there is no cut for which equation 3 is satisfied, indicated by "NS" (no signal) in the table. For $m_\rho = 1.78$ TeV the like-sign WW signal is smaller but the resonant WZ signal is much larger and satisfies the criterion with only 44 fb^{-1}. The worst case among the four models is at $m_\rho = 2.52$ TeV, as in our previous study. Because of the $l^+l^-l^+\nu$ background we now find that the optimum cut for that model, still in the like-sign WW channel, requires 105 fb^{-1} to meet the criterion, compared to 63 fb^{-1} in [2].

In table 1 we assumed 100% veto efficiency when the third lepton falls within the specified geometric acceptance. In table 2 we study the effect of veto inefficiency for $m_\rho = 2.52$ TeV. At 98% efficiency the effect is not great but at 95% $\mathcal{L}_{MIN}(WZ)$ is increased by 40%. For 90%, not shown in the table, $\mathcal{L}_{MIN}(WZ)$ would be nearly doubled, to 200 fb^{-1}. We presume that an aggressive $\simeq 98\%$ efficient veto is possible without significantly affecting the signal efficiency, but its feasibility requires further study.

Sensitivity to Collider Energy and Detector Coverage

The relative importance of the $\overline{q}q \to l^+\nu l^+l^-$ background to the W^+W^+ signal depends sensitively on the collider energy. At $\sqrt{s} = 14$ TeV it doubles the background for the optimum cuts and increases $\mathcal{L}_{MIN}$ for $m_\rho = 2.52$ TeV by 50%, from 63 fb^{-1} to 105 fb^{-1}. At higher energy the effect is smaller. For instance, for $\sqrt{s} = 40$ TeV and $m_\rho = 2.52$ TeV the $\overline{q}q \to l^+\nu l^+l^-$ process increases the background by 40% and $\mathcal{L}_{MIN}$ by 25%, from 5.2 fb^{-1} to 6.5 fb^{-1}. Since $\overline{q}q \to l^+\nu l^+l^-$ is dominated by $\overline{q}q \to WZ$ and $\overline{q}q \to W\gamma^*$, this energy dependence follows from their essentially two body phase space compared to

the four body phase space of the qqW^+W^+ signal and irreducible background.

We have made a preliminary exploration of the sensitivity to the acceptance region for the third lepton, with some unexpected results. For the results quoted above we assumed that wrong-sign electrons or muons could be detected for $\eta < 3$ and $p_T > 5$ GeV. If the coverage for the wrong-sign lepton is increased ambitiously to $\eta < 5$ the gain is surprisingly little. For $m_\rho = 2.52$ TeV with the cuts specified in table 1 the total background decreases by just $\sim 10\%$ and $\mathcal{L}_{MIN}$ only goes from 105 to 101 fb^{-1}. Reoptimizing the cuts we find $\mathcal{L}_{MIN} = 98$ fb^{-1}, a negligible change. This reflects the importance of the low p_T leptons.

On the other hand if we relax the transverse momentum cut for the wrong-sign lepton veto from 5 to 10 GeV, the effect is substantial. The result for $m_\rho = 2.52$ TeV with the table 1 cuts is to increase the $l^+\nu l^+l^-$ background by a factor ~ 2.5. Reoptimizing the cuts we now find that $\mathcal{L}_{MIN}$ would increase by 30% to 138 fb^{-1}.

$qq \rightarrow qqWZ$ Background to $qq \rightarrow qqW^+W^+$ Signal?

In our study of the WZ channel in [2] we found important contributions to both signal and background from $\overline{q}q$ annihilation ($\overline{q}q \rightarrow \rho \rightarrow WZ$ and $\overline{q}q \rightarrow WZ$) and from $qq \rightarrow qqWZ$. Because of the energy dependence of two and four body phase space, we found that $\overline{q}q$ annihilation dominates at the LHC while $qq \rightarrow qqWZ$ dominates (or would have) at the SSC. However even at the LHC the $qq \rightarrow qqWZ$ process is not negligible, contributing of order 30% of the signal and background. Since in this paper we have established a large background to W^+W^+ scattering from $\overline{q}q \rightarrow W^+Z$, we should also consider the possible background from $qq \rightarrow qqW^+Z$.

We have done so and find that it is very small. With $m_H \leq 100$ GeV and assuming that the wrong-sign lepton is unobservable for $\eta > 3$ or for $p_T < 5$ GeV, we find only 0.041 events per 100 fb^{-1} from $qq \rightarrow qqW^\pm Z$ for the cuts that optimize the W^+W^+ signal for $m_\rho = 2.52$ TeV (see table 1). We have not computed the complete $qq \rightarrow qql^\pm\nu l^+l^-$ amplitude since it would not be important even if it were a few times larger than the $qq \rightarrow qqW^\pm Z$ component.

Discussion

In evaluating the $qq \rightarrow qqWZ$ background to W^+W^+ scattering we considered the order α_W^2 standard model amplitude with $m_H \leq 100$ GeV. Just as for

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$\overline{q}q \to WZ$, we did not consider the enhanced WZ cross section that would occur if a ρ resonance were within the range of the LHC. That is because the precise question we are addressing is whether the standard model, with no strong force in the symmetry breaking sector, can contribute backgrounds that would be confused with strong WW scattering. Enhanced WZ production from strong dynamics in the WZ channel would indeed increase the apparent W^+W^+ signal, and the true W^+W^+ cross section could only be disentangled after measuring $\sigma(WZ)$. But since the overriding question initially is simply whether there is or is not strong dynamics in the symmetry breaking sector, this false amplification of the W^+W^+ cross section is actually advantageous: though it exaggerates the size of $\sigma(W^+W^+)$ it *is* truly an effect of strong symmetry breaking dynamics. As such it tends to offset the suppression of the signal by the $l^+\nu l^+l^-$ background. We will report elsewhere on a study of this pseudo-amplification of the W^+W^+ cross section as a function of m_ρ.

In our previous study we claimed, extrapolating from studies of the QCD corrections to $\overline{q}q \to ZZ$, that the lowest order amplitude gives a conservative estimate of the $\overline{q}q \to WZ$ background provided we use a central jet veto. This conjecture is now supported by a study of the next to leading order (NLO) cross section for WZ production.[11] As for ZZ production, the $qg \to qWZ$ process greatly enhances the single boson (W or Z) spectrum at high p_T, but the enhancement is associated with a momentum-balancing high p_T quark jet collinear with the second weak boson. It is therefore not relevant to our study because we use a central jet veto, which typically suppresses the single boson high-p_T spectrum to be at or just below the level of the tree approximation.[11] It would be useful to compute the NLO cross section for the cuts used here.

We are surprised by our own conclusion that $\overline{q}q \to l^+\nu l^+l^-$ is one of the two dominant backgrounds to strong W^+W^+ scattering assuming 100% veto efficiency for the third lepton, and is the dominant background for veto efficiency $\leq 98\%$, as shown in table 2. Despite the sizeable increase in our estimate of the background, we find that the LHC operating at 14 TeV and 10^{34} cm.$^{-2}$ sec.$^{-1}$ would be able in ~ 1 to $\sim 1\frac{1}{2}$ years to provide a significant strong scattering signal in the worst case scenario. The prospects might be better than we have indicated because of the "pseudo-amplification" of the W^+W^+ signal by enhanced strong scattering in the W^+Z channel, which remains to be studied in

detail. A critical experimental question requiring further study is the efficiency with which the extra leptons can be vetoed when they fall within the acceptance of the detector.

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Table 1. Minimum luminosity to satisfy significance criterion for $W^+Z + W^-Z$ and $W^+W^+ + W^-W^-$ scattering. For the like-sign WW channel we also specify the optimum cut on the like-sign leptons that gives $\mathcal{L}_{MIN}(WW)$, the corresponding number of signal and background events per 100 fb^{-1}, and the compositon of the background for the optimum cut. A central jet veto is included as specified in the text. Rejection of all events for which the third lepton falls within its acceptance region is assumed.

m_ρ(TeV)	1.78	2.06	2.52	4.0
$\mathcal{L}_{MIN}(WZ)$ (fb^{-1})	44	98	323	NS
$\mathcal{L}_{MIN}(WW)$ (fb^{-1})	142	123	105	77
WW Cut				
$\eta^{MAX}(l)$	1.5	1.5	1.5	2.0
$p_T^{MIN}(l)$ (GeV)	130.	130.	130.	130.
$[\cos\phi(ll)]^{MAX}$	-0.72	-0.80	-0.80	-0.90
WW Sig/Bkgd				
(events per 100 fb^{-1})	12.7/6.0	14.1/5.8	15.9/5.8	22.4/8.9
WW Backgrounds (%)				
$\bar{l}l\bar{l}\nu_l$	47	49	49	61
$O(\alpha_W^2)$	47	46	46	33
$O(\alpha_W\alpha_S)$	6	6	6	6

Table 2. Minimum luminosity to satisfy significance criterion for $W^+W^+ +$ W^-W^- scattering for $m_\rho = 2.52$ TeV, assuming 100%, 98% or 95% efficiency for the veto of wrong-sign charged leptons that fall within the acceptance region specified in the text. The optimum cuts and corresponding yields are shown as in table 1.

| Efficiency	100%	98%	95%
$\mathcal{L}_{MIN}(WW)$ (fb^{-1})	105	115	148
WW Cut			
$\eta^{MAX}(l)$	1.5	1.5	1.5
$p_T^{MIN}(l)$ (GeV)	130.	130.	160.
$[\cos\phi(ll)]^{MAX}$	−0.80	−0.80	−0.86
WW Sig/Bkgd			
(events per 100 fb^{-1})	15.9/5.8	15.9/7.9	12.1/5.6
WW Backgrounds (%)			
$\bar{l}\bar{l}\nu_l$	49	62	71
$O(\alpha_W^2)$	46	34	26
$O(\alpha_W\alpha_S)$	6	4	3

Figure Captions

Figure 1. The e^- rapidity (figure 1a) and transverse momentum (figure 1b) distributions corresponding to 100 fb^{-1} for $\overline{q}q \rightarrow e^+e^-l^+\nu_l$ where $l = e$ or μ. The cuts on the electron and the positive leptons are specified in the text, and 100% rejection is assumed for electrons within the geometric region specified for the veto. The dashed lines show the contribution from $\overline{q}q \rightarrow W^+Z$.

Figure 2. The number of events per 100 fb^{-1} for which both like-sign leptons have transverse momentum greater than p_T^{MIN}. The rapidity and azimuthal angle cuts on the like-sign leptons are at the optimum values specified in table 1 for $m_\rho = 2.52$ TeV. All events with the third lepton inside its acceptance region are rejected. The solid, dashed, dot-dashed, and dotted lines are respectively the signal and the backgrounds from $\overline{q}q \rightarrow l^\pm\nu_l\overline{l}l$ and from $qq \rightarrow qqW^+W^+/W^-W^-$ in orders α_W^2 and $\alpha_W\alpha_S$.

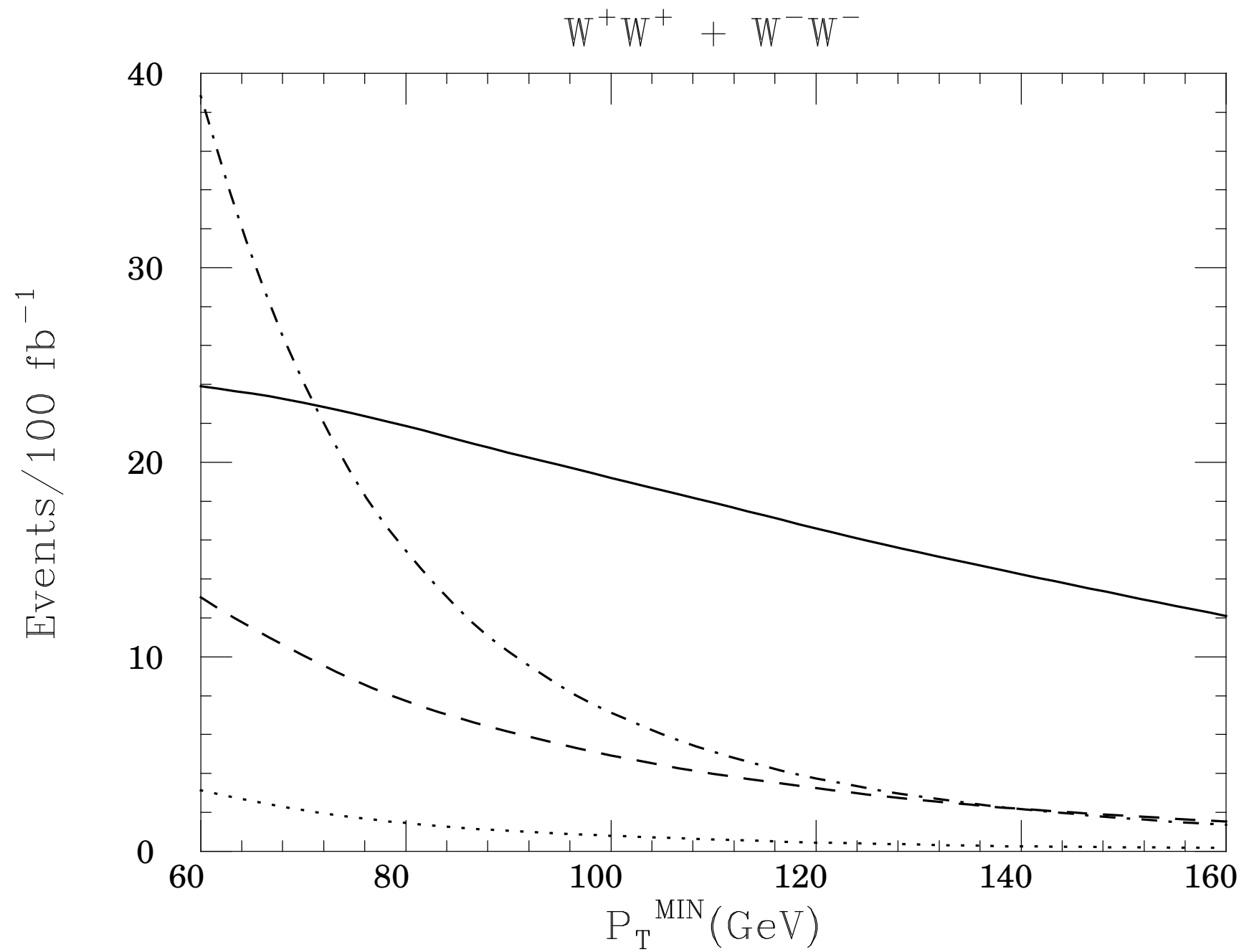This figure "fig1-1.png" is available in "png" format from:

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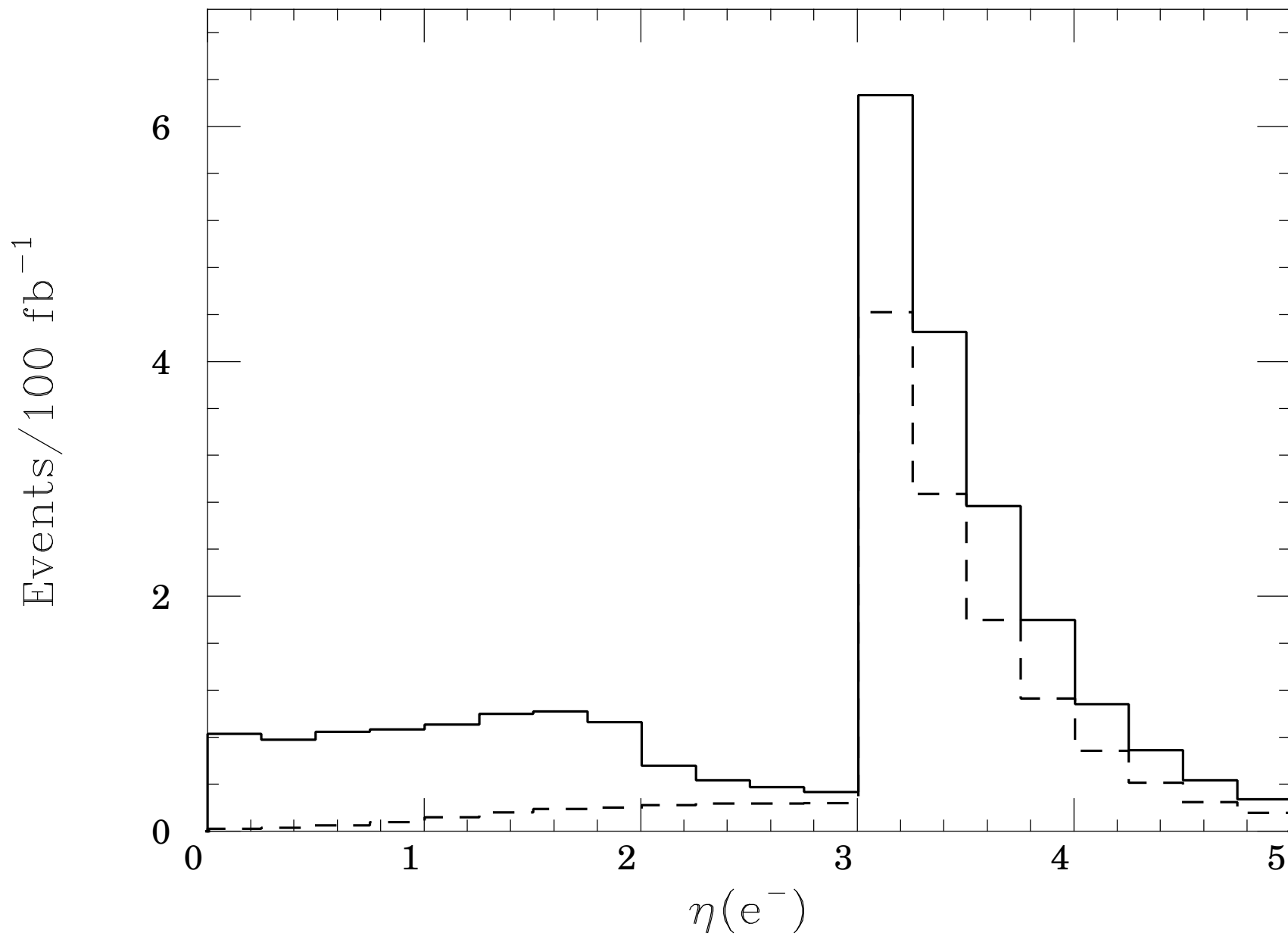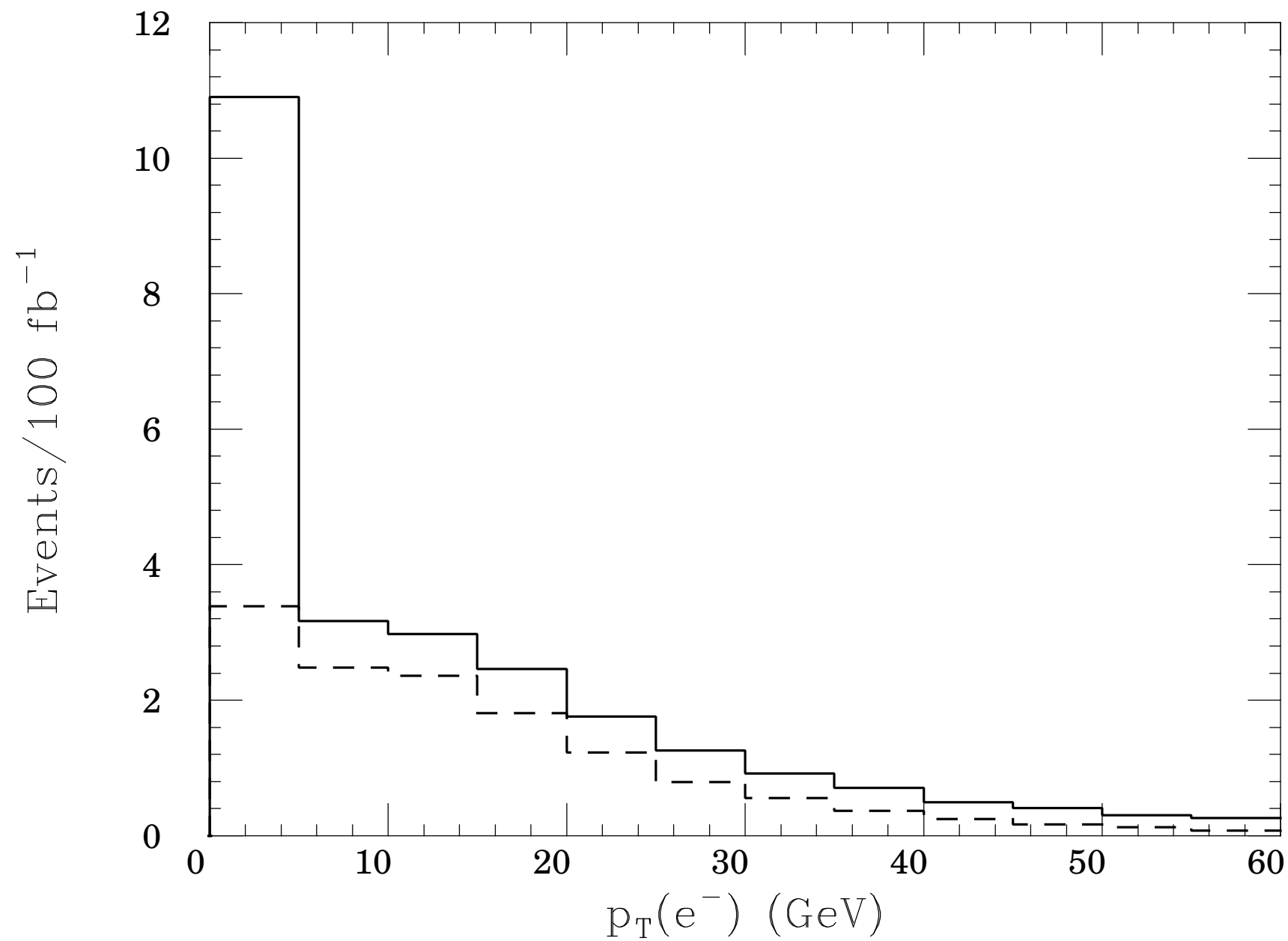
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$W^+W^+ + W^-W^-$

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